Simulating the Black Sea 7Be transport with nested general circulation models

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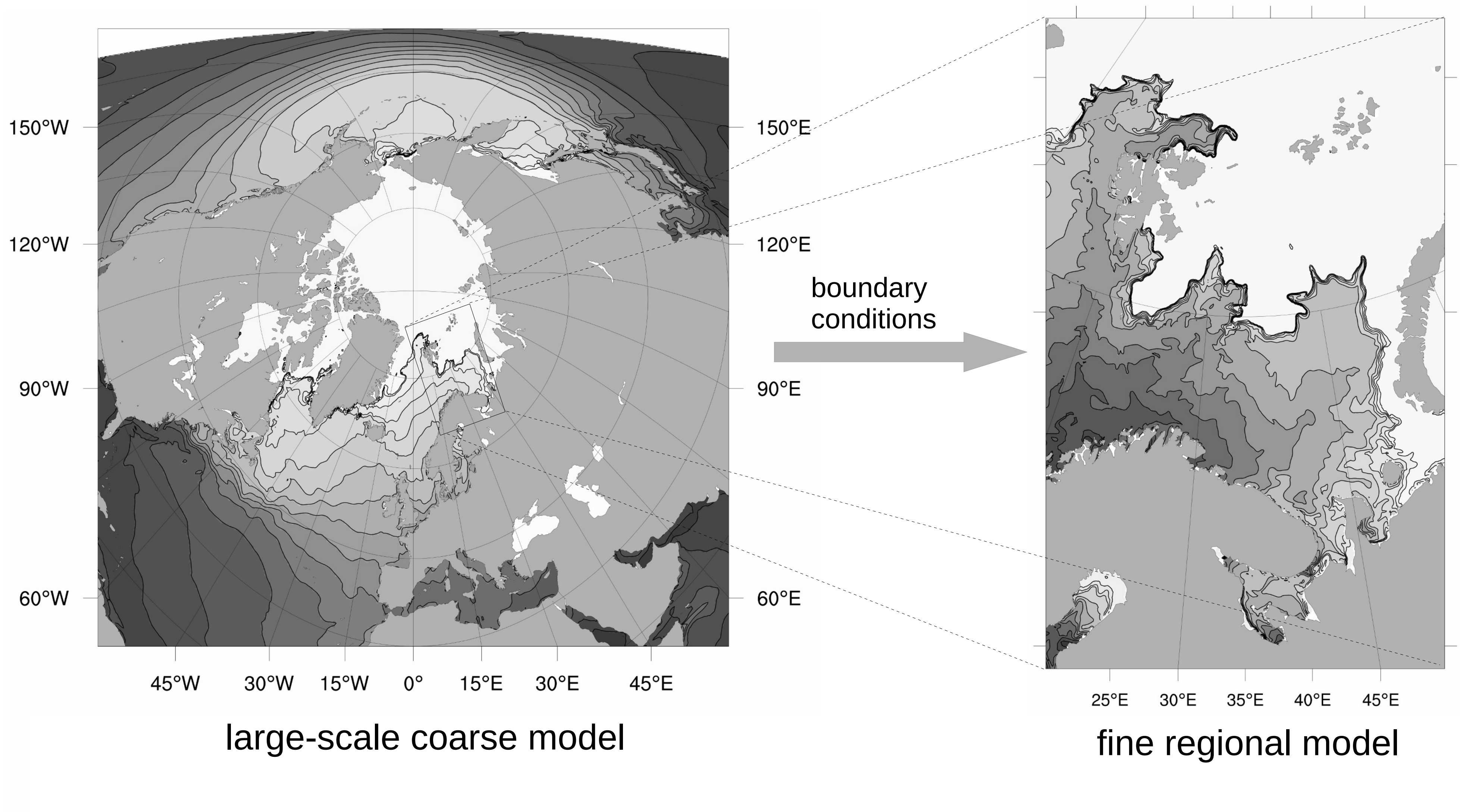
Nested ocean modelling — a tool for dynamical downscaling



Koromyslov et al., 2017

Nested ocean modelling problems

mathematical

boundary information inconsistent in the two models

- numerical instabilities
- spurious wave reflection
- solution distortion
- eddy speed mismatch

Need for methods of coordinating the model solutions and radiate away the spurious waves

computational

high demands for data exchange frequency

- diurnal cycle
- inertial oscillations
- coupling stability
- shock reduction, etc.

Need for fast and flexible inter-model data exchange services

MHI Black Sea basin general cicrulation model with 7Be lifecycle

$$u_t - (\xi + f)v + wu_z = -g\varsigma_x - \frac{1}{\rho_0}(P' + E)_x + (v_V u_z)_z + F^u$$

$$v_t + (\xi + f)u + wv_z = -g\varsigma_y - \frac{1}{\rho_0}(P' + E)_y + (v_V v_z)_z + F^v$$

$$u_x + v_y + w_z = 0$$

$$\varsigma_t + \int_0^H (u_x + v_y)dz = (\mathrm{Pr} - Ev)$$

$$P = g\rho_0\varsigma + g\int_0^z \rho dz = g\rho_0\varsigma + P'$$

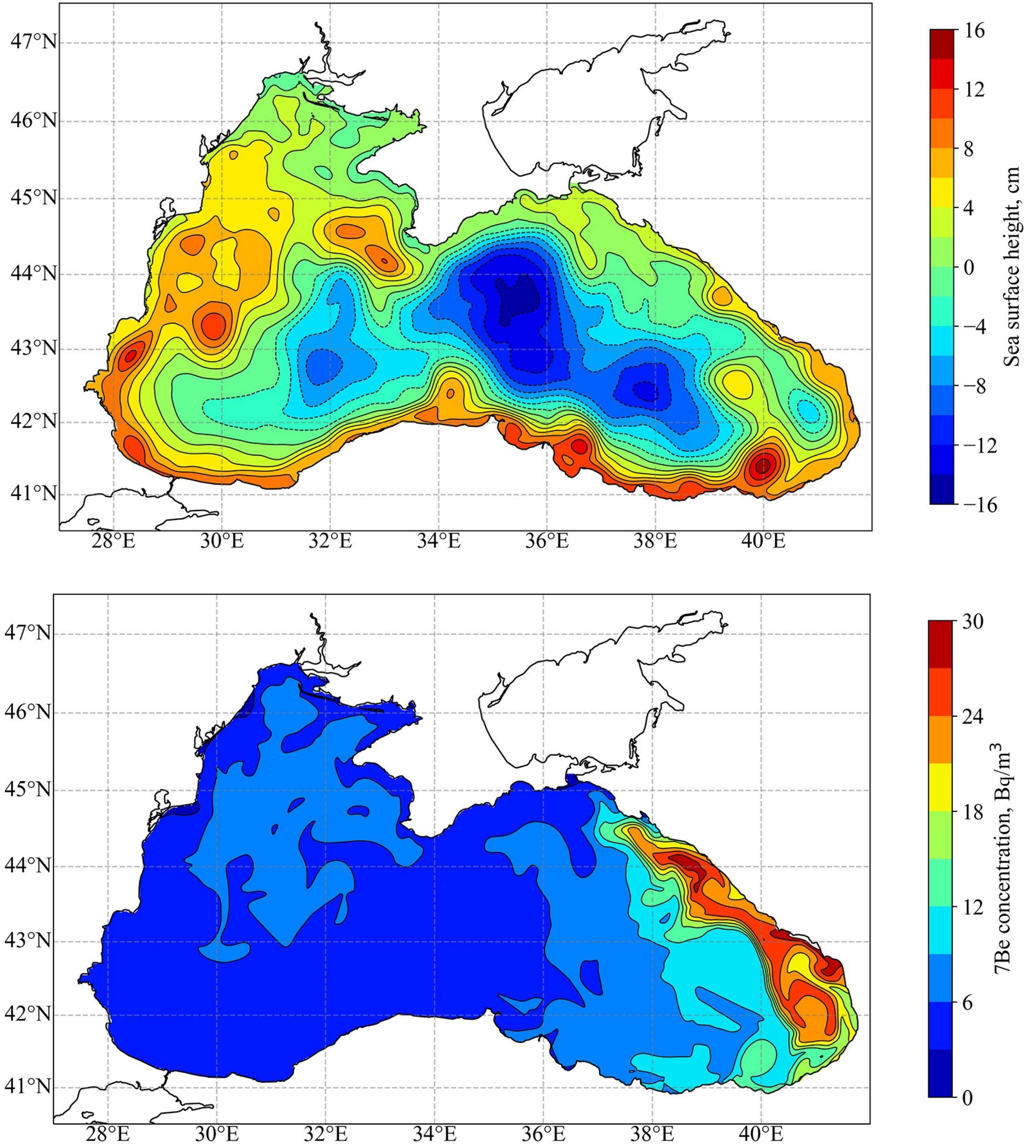
$$T_t + (uT)_x + (vT)_y + (wT)_z = \kappa^H \nabla^4 T + (\kappa^T T_z)_z$$

$$S_t + (uS)_x + (vS)_y + (wS)_z = \kappa^H \nabla^4 S + (\kappa^S S_z)_z$$

$$\rho = \rho_0 + \alpha_1^T T + \alpha_1^S S + \alpha_2^T T^2 + \alpha^{ST} ST$$

$$C_t + (uC)_x + (vC)_y + ((w + pW_s)C)_z = A^H \nabla^4 C + (A^V C_z)_z - \lambda C$$

- Fortran 90
- C-type staggered grid with 1.6 km resolution, 27 z-levels
- Boussinesq, hydrostatic and incompressibility approximations
- Leap-frog+Matsuno scheme, 96 s timestep
- TVD advection
- Biharmonic horizontal mixing
- Mellor-Yamada 2.5 turbulence
- ERA5 atmospheric forcing
- Climatology rivers and straits
- ARGO+ship profiles and satellite SST assimilation
- Dissolved+adsorbed 7Be
- Wet+dry 7Be deposition
- ERA5+MODIS+cosmic rays 7Be forcing



The Black Sea surface height anomaly and 7Be concentration by the simulation of the basin model, 19 July 2016

MHI high resolution local model

Similar as the basin model, except for:

- 560 m horizontal resolution
- 10 s timestep
- Centered difference advection
- Laplacian horizontal mixing
- Pacanowski-Philander vertical mixing
- Dirichlet open boundary conditions where water inflows
- Where water outflows:
  - Neumann free flow velocity
  - Orlanski conditions for scalars

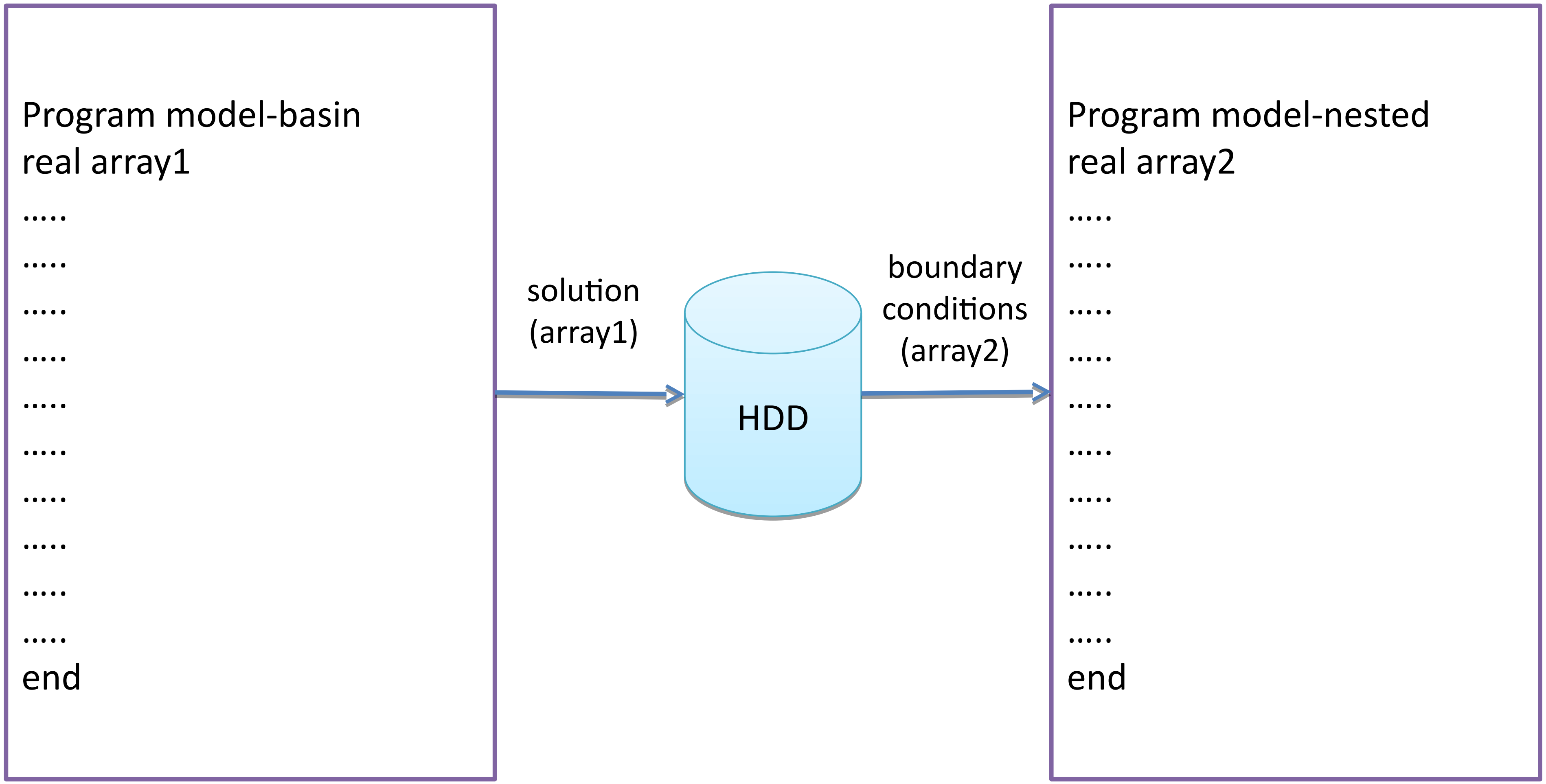
Orlanski conditions for a scalar field φ in case of zonally oriented boundary

$$\frac{\partial \phi}{\partial t} + c \frac{\partial \phi}{\partial y} = 0$$

Velocity of disturbance transfer

$$c = \begin{cases} \frac{\Delta y}{\Delta t}, & \text{if} \quad -\frac{\phi_t}{\phi_y} > \frac{\Delta y}{\Delta t} \\ -\frac{\phi_t}{\phi_y}, & \text{if} \quad 0 \leqslant -\frac{\phi_t}{\phi_y} \leqslant \frac{\Delta y}{\Delta t} \\ 0, & \text{if} \quad -\frac{\phi_t}{\phi_y} < 0 \end{cases}$$

Nested modelling: serial approach



Compact Modelling Framework: designation

Separation of **modelling algorithms** and **service procedures** allows to distribute workload, create transparent code and independently develop both directions.

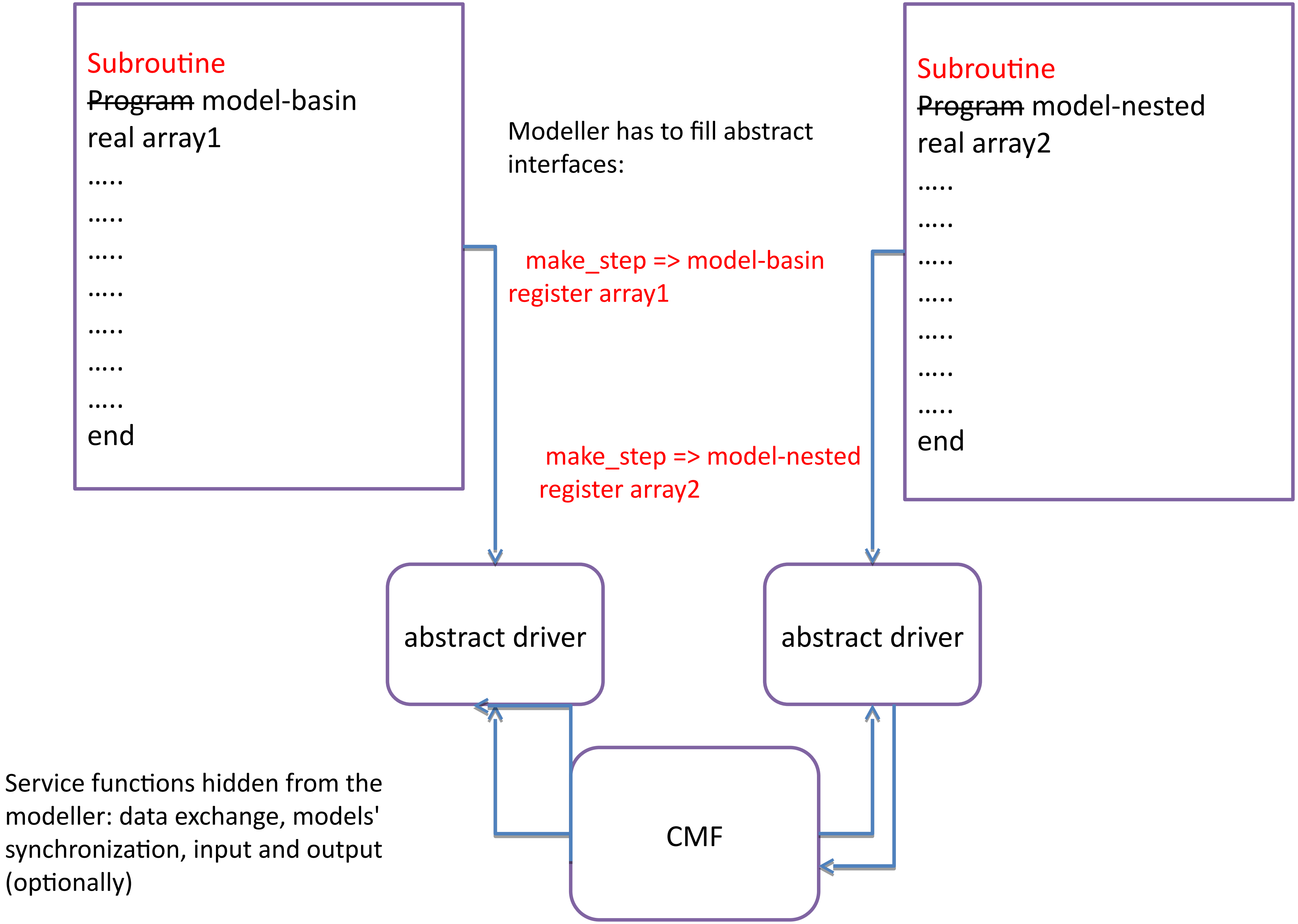
Services implement:

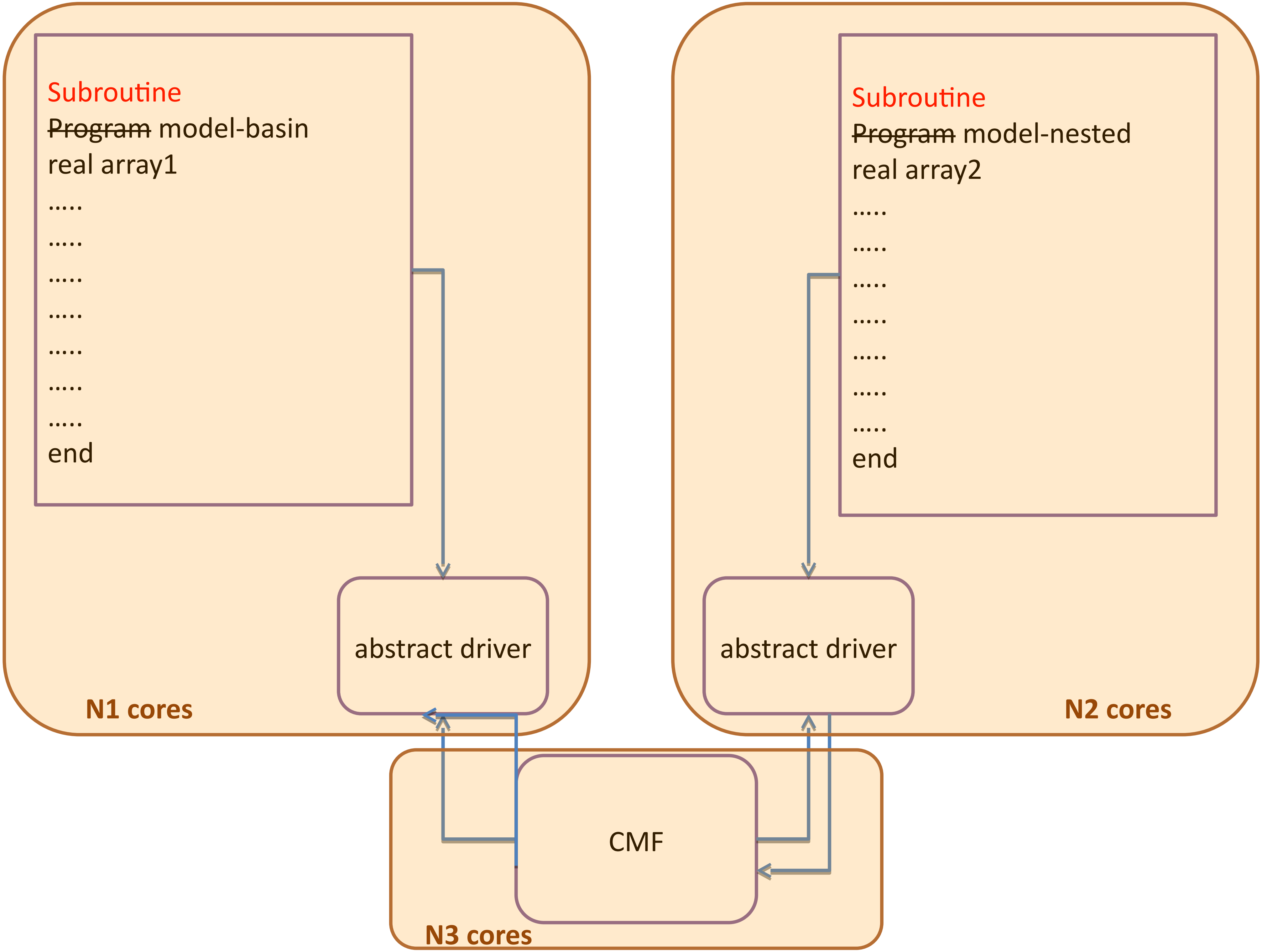
- Inter-model data exchanges
  - at physical interfaces
  - nesting
- Grid-to-grid interpolation
- Models' synchronization
- Pre- and post-processing
- Data assimilation
- Input and output
  - initial conditions
  - external forcing
  - fast diagnostics
  - control points for restart
- etc ...

Model component methods:

- Register
  - model grid
  - parallel decomposition
  - model arrays
  - experiment parameters
- Allocate arrays
- Initialize arrays
- Make time step
- Finalize

Abstract driver approach




Subroutine
~~Program~~ model-basin
real array1
.....
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.....
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.....
.....
.....
end
abstract driver
N1 cores
Subroutine
~~Program~~ model-nested
real array2
.....
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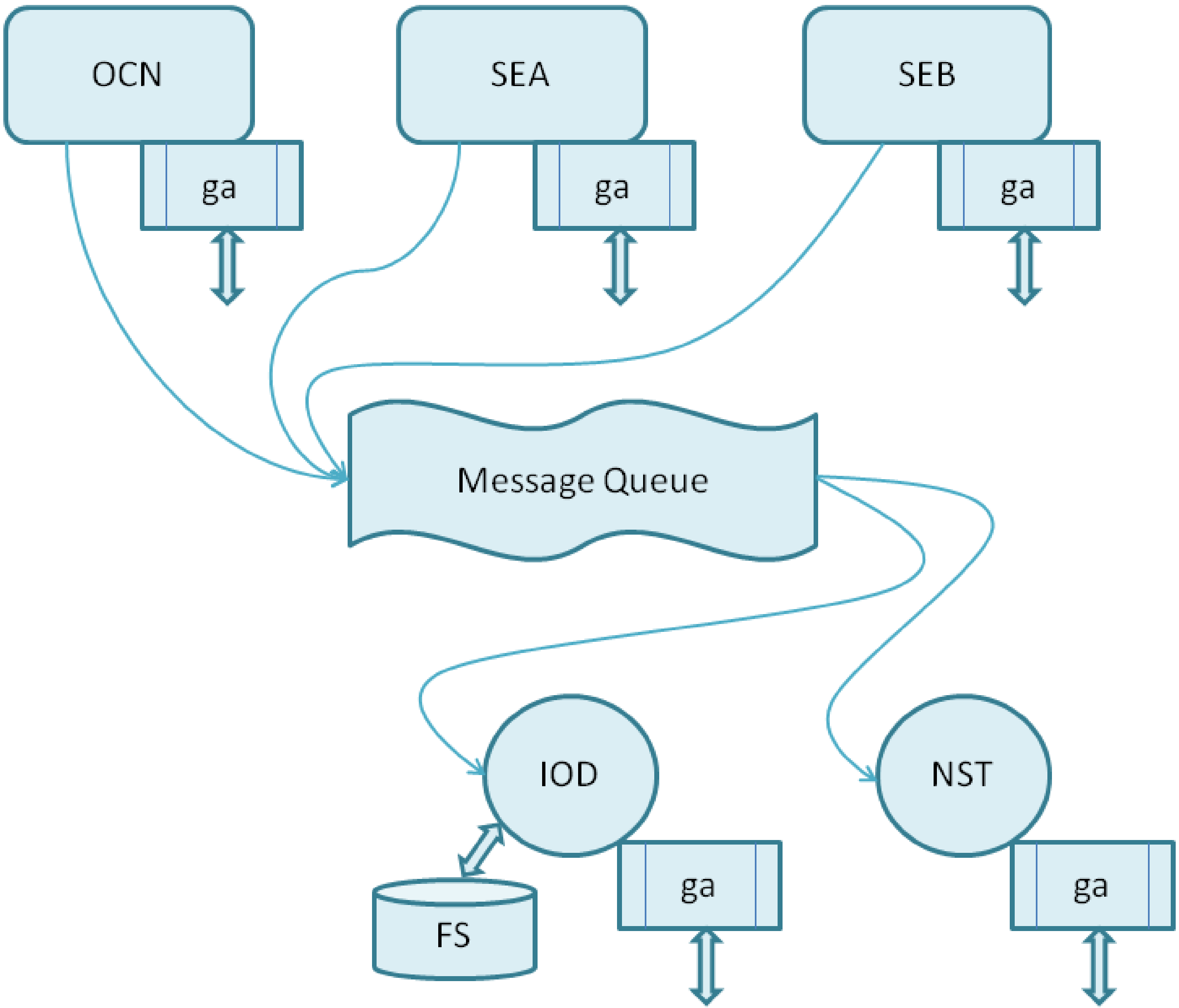
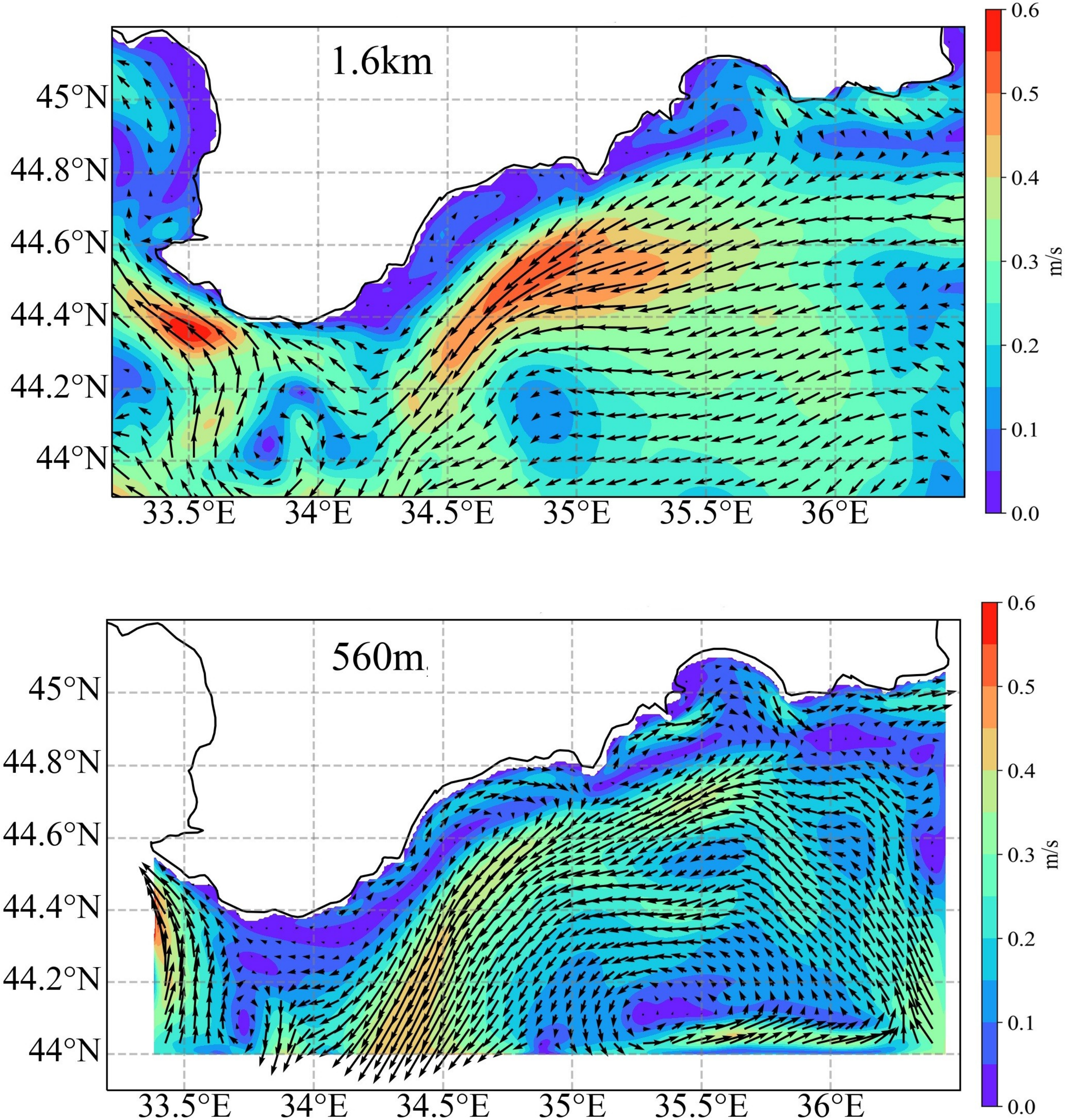
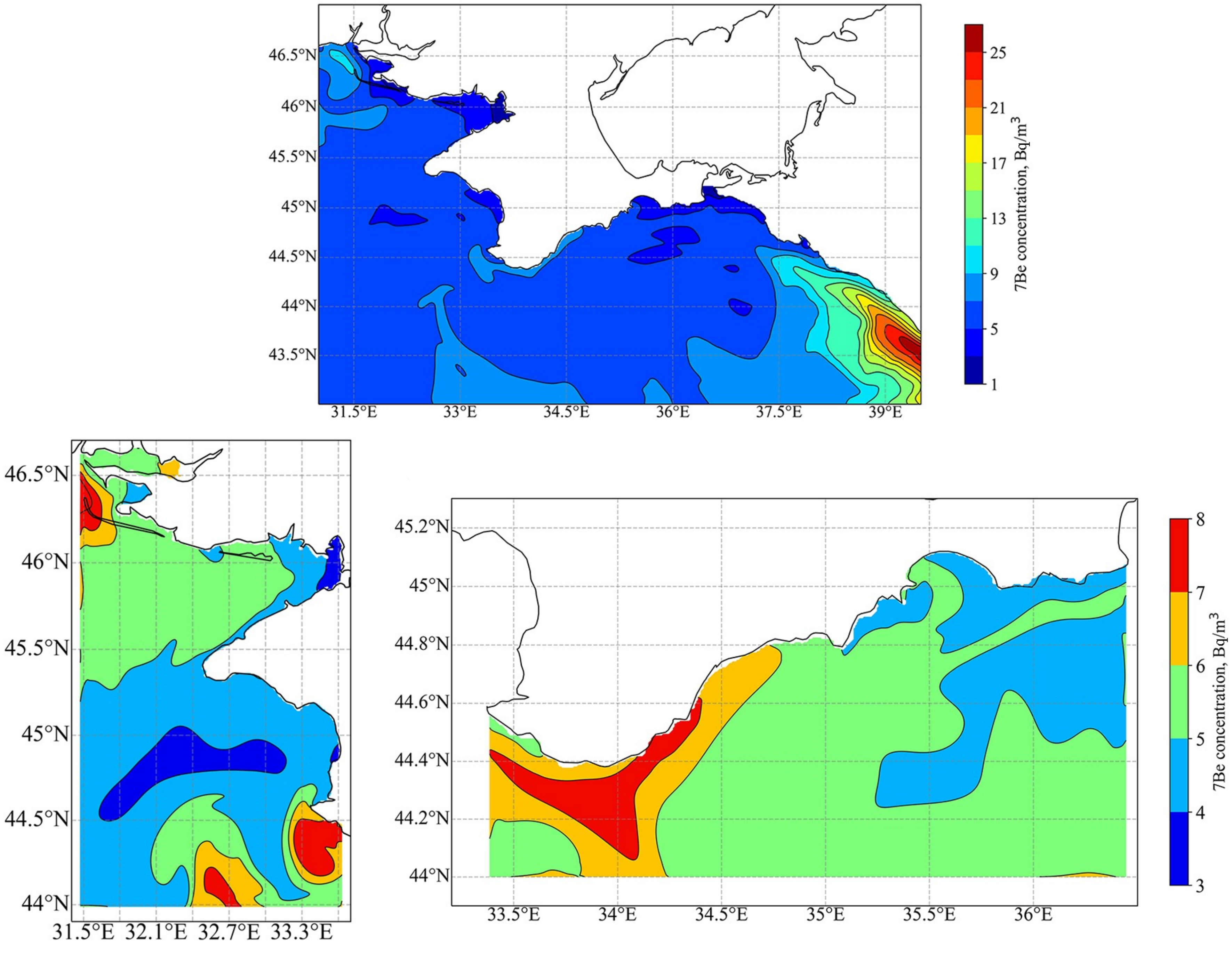
end
abstract driver
N2 cores
CMF
N3 cores

CMF: Service-oriented architecture and Global Arrays back-end

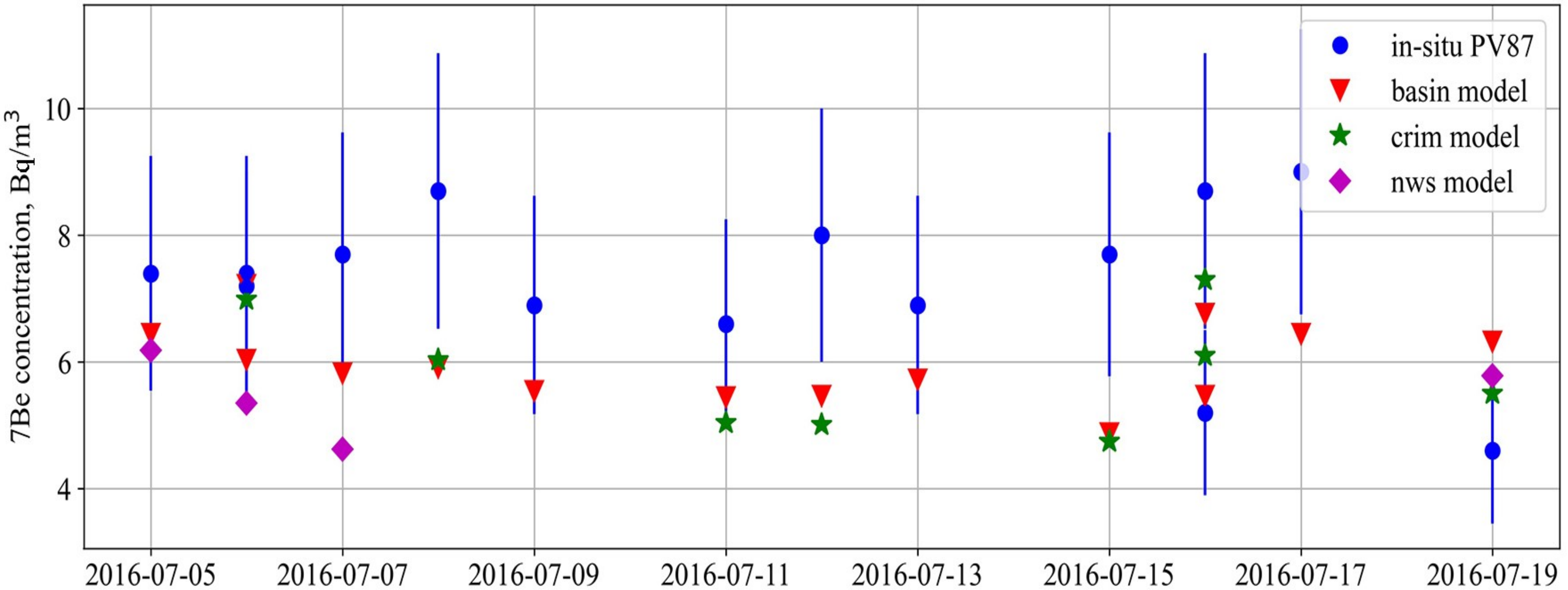




Current fields at 3 m, calculated with resolutions of **1.6 km** (every 6th arrow shown), **560 m** (every 8th arrow shown) on 8 July 2016



7Be concentration at 2.5m depth by the basin model and nested regional models on 8 July 2016



7Be concentrations by simulation and observations during the cruise of R/V “Professor Vodyanitsky” in July 2016

Thank you!

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with financial support of the Russian Science Foundation
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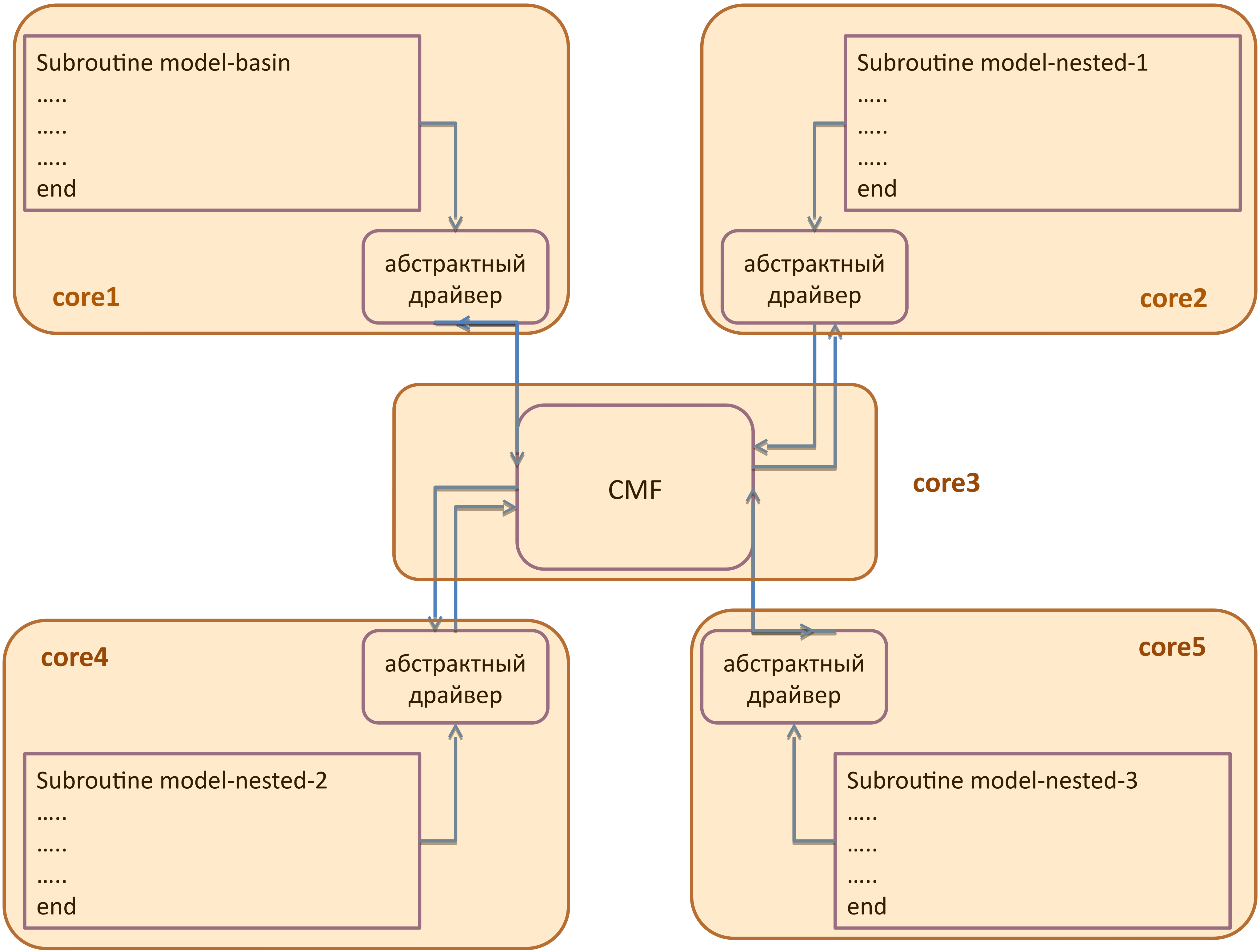
Subroutine model-basin
.....
.....
.....
end
абстрактный драйвер
core1
Subroutine model-nested-1
.....
.....
.....
end
абстрактный драйвер
core2
CMF
core3
core4
абстрактный драйвер
Subroutine model-nested-2
.....
.....
.....
end
core5
абстрактный драйвер
Subroutine model-nested-3
.....
.....
.....
end